EFFICIENT COMPUTATIONAL METHODS FOR THE INVESTIGATION OF VASCULAR DISEASE

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Predictive medicine in which the physician utilizes computational tools to construct and evaluate a combined anatomic/physiologic model to predict differential changes in vascular flow for alternative treatment plans for an individual patient's surgery is increasingly becoming a viable option. Investigating arterial hemodynamic conditions by computational techniques requires the application of accurate and efficient numerical schemes. The complexity of the coupled blood fluid-structure interaction system in terms of both the geometry and the model equations places high demands on the numerical methods that are employed.

We use a stabilized finite element Streamline-Upwind/Petrov-Galerkin method (SUPG) introduced by Hughes et al. (1986) in 3D for the incompressible transient Navier-Stokes equations on unstructured grids that is also suited to perform in a parallel computing environment.
To further improve the method's efficiency we have implemented an anisotropic adaptive finite element method for the flow equations, hereby assuring accurate simulation results at minimal computational costs. The novel method is based on *residual* a posteriori error estimators together with directional refinement/coarsening information. The latter are derived from second order derivatives (hessians) of the computed fluid velocity field. A posteriori error estimators are directly retrieved from the computed solution fields and provide information on the local distribution of the discretization error. This information is used to assign elements to be split/coarsened in order to simultaneously obtain a more accurate solution and reduce computational expenses.
In addition, the directional information from the hessians is exploited to further economize computational resources by only allowing refinement of the previously selected elements in a certain direction. The resulting anisotropic meshes assure higher flow solution accuracy with fewer elements compared to conventional methods based on isotropic refinement.

The software is designed in such a way that future users will be able to choose among a variety of different refinement strategies that deal with the transient behavior of the system. Currently we have implemented a strategy that uses a spatially refined mesh in the current time step to predict the (quasi optimal) mesh for the subsequent time step. By applying this strategy in a more general way, that is, collecting the errors over representative periods of the flow (in this case the cardiac cycle) we account for the transient, quasi-periodic nature of the flows.
We demonstrate the applicability and validation of the method on a set of blood flow models that are derived from medical imaging data.